Report of the Panel on

Reducing Risk
In
Ballistic Missile Defense
Flight Test Programs

27 February 1998

Reducing Risk
in
Ballistic Missile Defense Flight Test Programs

Final Report

Objectives

- Independently review current and planned preflight testing practices for hit-to-kill (HTK) ballistic missile defense (BMD) interceptor programs, assess their adequacy, and identify any innovations that might be needed to provide a high level of confidence that each flight test will be successful
- Identify best practices for the National Missile Defense (NMD) program vs. specific program recommendations
- Sponsors
  - Director, Operational Test and Evaluation (DOT&E)
  - Director, Test, Systems Engineering and Evaluation (DTSE&E)
  - Director, Ballistic Missile Defense Organization (BMDO)

This study was initiated by the sponsors to address risk in the flight test programs of BMDO's hit-to-kill (HTK) ballistic missile defense (BMD) systems. The four systems are the Theater High Altitude Area Defense (THAAD); the Patriot-3 System with its Patriot Advanced Capability-3 (PAC-3) missile; the AEGIS LEAP Interceptor (ALI) Program, which is a risk-reduction program within the Navy Theater Wide (NTW) Defense System; and BMDO's NMD program. This study was motivated by a series of flight test failures in some of these programs—failures which indicated a high level of risk. These failures have significantly delayed the planned fielding of BMD systems.

The study group members examined current theater missile defense (TMD) programs to address the issues. However, the task was not to evaluate these programs. Rather, the task was to take lessons from these programs that could and should be applied to the NMD program.

Observations about the current state and future progress on these individual TMD programs are relevant to the findings of the study and are included here. We focused on those observations that are common to more than one program and that could, therefore, be important warning flags for the NMD program.

Study Group Members

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The study group was composed of members who have extensive experience in the development, testing, and operational employment of complex systems.

We applied this experience in examining current HTK BMD programs. The goal was to extract lessons from these programs and other complex programs and apply these lessons to the NMD program.

Tasks

- Review the historic test and evaluation (T&E) paradigms for testing missile systems to see if these paradigms are still relevant, practical, and affordable
- Review past and present programs to identify factors that
  - Contribute to maximizing the amount learned from each flight test
  - Enhance the success of each flight
- Examine how best to identify the most likely failure modes and the key factors in the success (or lack thereof) of interceptor flight tests
- Recommend practices and preflight test options that, if implemented by BMDO, would mitigate the risk of flight test failures
- Address how the NMD Joint Program Office (JPO) could best use additional resources allocated in the Quadrennial Defense Review (QDR)

These tasks further defined the overall objective.

As previously indicated, to understand the historic T&E paradigm, the study group relied extensively on members' broad and extensive experience in dealing with complex development programs. The primary focus was on reviewing current relevant programs, relating the results of this review to history and experience, and applying the lessons to the NMD program.

We found that the processes and approaches to identify and preclude failure modes in BMD programs are not fundamentally different from the long-standing, sound design and management approaches used for other successful systems. However, the demands of the HTK end game require a higher level of fidelity in the ground simulations [both digital and hardware-in-the-loop (HWIL)] to surround the variables and uncertainties of the dynamics and target presentation.

This report presents specific findings on practices and preflight test options and on NMD program areas that require increased funding emphasis.

Report Outline

- Objectives, Sponsors, and Study Group Members
- Tasks
- Key Judgments—Overarching Observations
- Recommendations for Reducing Flight Test Risk and Fielding Capability Expeditiously
  - All BMD programs
  - NMD
- Findings: Responses to Specific Questions in the Tasking
- Specific Program Reviews
  - Peacekeeper ICBM Program
  - THAAD
  - NTW Theater Ballistic Missile Defense (TBMD)
  - Patriot Missile Program
  - The NMD Program
- Meetings and Site Visits
- Glossary

In keeping with the study group objectives, the Key Judgments are overarching study group views based on the aggregate of HTK programs examined.

Specific recommendations are provided for reducing the test risk in the NMD program. Findings that address the specific questions in the tasking are also provided.

In addition, we reviewed practices from other complex programs. In this category, even though the report specifically discusses only the Peacekeeper Intercontinental Ballistic Missile (ICBM) program and the earlier Sprint Missile program, our experiences with other programs provide similar conclusions.

The sections on specific BMD programs highlight some of the sources of the lessons that we believe are particularly relevant to the NMD program.

Key Judgments—
Overarching Observations

This section begins with the Key Judgments. These Key Judgments emanated from what the study group regarded as the most overarching in the aggregate of the programs examined and the experiences of the study group members. These are also those most important as lessons for NMD.

Following the Key Judgments, overarching recommendations are provided and then specific questions are addressed—again using the lessons from the programs examined and experiences of the study group members.

Key Judgments (1 of 6)
The Program Management Environment

- HTK remains a difficult technical challenge
  - Prudent management demands careful attention to avoid increasing the inherent risk further
- Failures to date have little to do with HTK vehicle technology but have prevented the demonstration of that technology
- The flight test record to date has not demonstrated that the technology has reached the state of maturity needed for operational systems
  - Homing Overlay Experiment (HOE): 1 intercept in 4 attempts
  - THAAD: 4 intercept attempts, 4 failures
  - Lightweight Exo-Atmospheric Projectile (LEAP): 4 intercept attempts, 4 failures
  - Extended Range Interceptor (ERINT): 2 intercepts in 3 attempts at theater ballistic missile (TBM) targets
  - Exo-atmospheric Reentry Vehicle Intercept System (ERIS): 1 intercept in 2 attempts

The study group's most fundamental finding and the finding most relevant to the NMD program is that the general planning and execution of the THAAD and LEAP programs are inconsistent with the difficulty of the task. These programs are pursuing very aggressive schedules, but these schedules are not supported by the state of planning and testing.

Specifically, the *perceived* urgency of the need for these systems has led to high levels of risk that have resulted in delayed deployments because of failures in their development test (DT) programs.

After more than a dozen flight tests, the most obvious and visible consequence of this approach is that we are still on "step one" in demonstrating and validating HTK systems. Failures having little to do with the kill vehicle (KV) performance—where the technology should be in hand—have precluded demonstrating that weapons systems are capable of reliably hitting a ballistic missile warhead. And even when this first step is achieved, these programs will still have to go through steps two and three: demonstrating reliable HTK at a weapon system level and demonstrating reliable HTK against likely real-world targets.

Failures to date reflect inadequate design and fabrication discipline.

Key Judgments (2 of 6)
The Program Management Environment

- Programs have been characterized by pressures for higher risk approaches to meet an "urgent need" for early capability [e.g., THAAD User Operational Evaluation System (UOES)], but this capability is inconsistent with the technical challenge
- Program "urgency" is reflected in less-than-minimal or highly compressed planned flight testing
  - THAAD: 20 flight tests in 24 months
    - Now 13 flight tests, with the schedule continuing to slip
    - 1 intercept required to exercise the 40-missile UOES buy
  - NTW: 9 flight tests in 48 months
  - Patriot PAC-3: 16 tests in 2+ years (11 BMD)
  - NMD: 6 tests in 2+ years before readiness-to-deploy review

Peacekeeper program planned 20 flight tests in 4+ years (flew 19)

The "early capability" approach demands operational capability before system design is completed through the Engineering Manufacturing Development (EMD) phase. This approach is inconsistent with the complexity of the task and has, thus far, not accelerated operational capability. Instead, the added risk has produced little discernible benefit and has actually delayed operational capability.

The most convincing evidence of the risk pressures from this approach is found in the test planning. This planning is characterized by either less-than-minimal testing or highly compressed testing or both.

For THAAD, the original plan was 2 years to the first test flight and then almost a test flight per month for the next 2 years. Thus far, the response to failures has been to reduce the testing in an attempt to maintain the schedule. The NTW test schedule is not compressed, but the number of planned tests is not consistent with the task. The Patriot program, which, in most respects, is carefully planned and is building on a legacy of well-developed processes, also has been forced into the less-than-minimum test mode.

Current planning for the NMD test program is even more optimistic than the theater HTK programs.

As noted here, as a benchmark, the Peacekeeper program—certainly no more technically challenging than HTK—responded to intense schedule pressure with a clearly adequate and well-paced test program and delivered the required capability on schedule.

Key Judgments (3 of 6)
Information Sharing

- Sharing information among programs and Services is deemed vital to the efficiency and effectiveness in solving the very difficult problems of HTK BMD
- Competition among programs should not be allowed to interfere with cross-tell of information
  - BMDO needs to enforce cross-tell vigorously
- A reliable and repeatable process is needed for transferring "tribal knowledge" from one project management to another
  - For example, the design and engineering processes that have been used for a long time in the Patriot program can benefit the other HTK BMD programs
  - Use of "graybeards" for this purpose is useful but should not be "the system"

The study group was struck by the similarities among the challenges and the similarities among the likely solutions to flight test failures. However, we also found that lessons, approaches, and solutions used in one program were often not available for other programs with similar challenges.

BMD programs rely heavily on the "graybeard" community to transfer "tribal knowledge." While such groups can provide useful insights and advice, they cannot be a substitute for effective formal and informal cross-tell at the management and engineering levels among programs facing similar challenges. This activity needs to be a high-priority responsibility of BMDO.

Key Judgments (4 of 6)
Developmental Test Philosophy

- The mindset that risky "key demonstration" tests can prove readiness for early deployment has permeated some BMD DT programs and is a key departure from the test paradigm that has proven to be successful in other complex programs
- BMD programs need to pay more attention to ground testing, simulation, and analyses to reduce known areas of uncertainty to be resolved in flight tests to only those issues that cannot be investigated with ground testing. The more limited the flight testing program, the more essential it is to reduce uncertainty
- The philosophy appears to be to plan for a single test in each "regime" (e.g., exo, endo, long-range, short-range) and then move on
- There is a need to hold the test vehicle configuration as constant as possible for a needed *series* of tests

The rush to failure in flight testing has been partially caused by a fundamental misunderstanding of the purpose of developmental testing. Some of these tests were treated as demonstrations of known capabilities where "fly to verify" was the purpose. In practice, the unknowns made them "fly to learn" experiences. The "demonstration mindset" was evident in flight tests conducted without complete component qualification and ground testing. One program office espoused the concept of "test a little, learn a lot." The drive for early capability based on minimum capability demonstration has been a factor in this "key demonstration" mentality—that is, a single success is regarded as a large step forward and becomes the criteria for a key program decision, such as exercising an option to buy operational missiles. This approach and mindset are sharp departures from experience on successful flight test programs that have followed the practice of "learn a lot" and then "test to verify."

BMD programs need to pay more attention to reducing the uncertainties to only those issues that cannot be tested on the ground or adequately simulated. One example is that none of the infrared (IR) HTK programs (THAAD, ALI, and NMD) have exploited or plan to exploit existing high-fidelity scene generation capabilities to exercise their hardware to the maximum advantage. Test planning needs to be very explicit in identifying the ground test and flight test needs for each key issue.

In general, the test programs are designed to provide a single shot in each operating regime. While back-up hardware is available— in most cases—to repeat tests, the single-shot planning produces unrealistic test schedules and pressures to move on despite failures to achieve test objectives.

Key Judgments (5 of 6)
Added Risk Is Not Working

- The strategy of accepting a high level of risk to shorten schedule time has been counterproductive
  - THAAD is 4 years behind schedule
  - NTW has just delayed its deployment date and has begun a risk-reduction program (ALI)
  - The path to NMD operational capability is largely undefined
- Historically, the most likely cause of program slips has been high technical risk

The study group was not surprised to find that accepting higher risk is not accelerating fielded capability. The virtually universal experience of the study group members has been that high technical risk is not likely to accelerate fielded capability. It is far more likely to cause program slips, increased costs, and even program failure.

Key Judgments (6 of 6)
The NMD Program

- Schedule and cost pressures on NMD have created a planning environment at least as optimistic as that which has lead to test failures and delays in TMD programs
- The NMD program consists of a series of very difficult challenges
  - Although NMD activity has been ongoing for a long time, there has not been a coherent, consistent path and a realistic plan leading to a deployed system
  - There are high schedule risks and inadequate test assets and testing planned in the 3 + 3 formulation
  - In the judgment of the study group, successful execution of the 3 + 3 formulation on the planned schedule is highly unlikely. The program will benefit from the earliest possible restructuring to contain the risk

For NMD, the schedule and cost pressures inherent in the 3 + 3 formulation and the system requirements are inherently even more severe than those for the TMD programs that have experienced excessive flight test failures.

To succeed, the NMD program must meet a series of formidable challenges. The effort to meet these challenges must emanate from a clear set of requirements, consistent resource support (which includes an adequate number of test assets), well-defined milestones, and a rigorous test plan. The study group believes that current NMD program is not characterized by these features and is on a high-risk vector. It will benefit from the earliest possible restructuring to a more achievable set of goals.

Recommendations for Reducing Flight Test Risk and Fielding Capability Expeditiously

The study group's initial attempt to distinguish between best practices and specific program recommendations became counterproductive. Hence, the following slides provide specific recommendations for implementing best practices in BMD programs. We have emphasized those practices most relevant to the NMD program.

Recommendations for Reducing Flight Test Risk All BMD Programs (1 of 4)

- Put the programs on realistic schedules now. Do not wait for further failures
  - Schedules must be consistent with historical programs
  - Schedules can be more aggressive, but *only* if justified by the new processes or approaches that support shorter development times
  - Accelerating schedules by simply adding risk carries a very high risk of failure
- Focus intensely on *sequentially* demonstrating that
  - The technology for the selected approach to HTK is ready for operational systems
  - The technology is operationally reliable
  - The technology is robust to at least the first layer of countermeasures
- Require a detailed test plan that includes a full set of ground simulation and tests (to include HWIL) tied to each flight test objective. Include the test facility requirements and plan

These first sets of recommendations apply to all BMD programs, including NMD.

To reduce the pressure on the programs "to shoot" before progressing to a reasonable probability of success, BMDO must put its programs on realistic schedules before failures occur. These schedules should be consistent with those of past successful programs. Aggressive schedules should be allowed *only* if they can be justified by new processes or approaches that will support accelerated schedules.

For the near term, the BMDO programs should focus on demonstrating that HTK technology is viable and that HTK against simple targets can be achieved reliably. Only after this has been demonstrated can the programs continue to demonstrate that the proposed weapon system is operationally feasible. As noted in the Findings Section, some requirements on systems result from a desire to demonstrate operational capability before the system design and development have been completed. Relaxing these requirements would raise the probability of success in the first step of demonstrating HTK. Finally, the weapon system must demonstrate that it is robust to a first layer of countermeasures.

While all the programs have a test plan, most programs do not make use of the ground simulation and testing warranted by the difficulty of the in-flight task.

Recommendations for Reducing Flight Test Risk All BMD Programs (2 of 4)

- Ensure that test planning—ground and flight—reduces the test flight uncertainties to only those issues that must be resolved in flight. Flight test treatment of other technical issues should be verification, not surprises
- Eliminate the demand for fielded operational capabilities in advance of EMD. Regardless of the desire for "early" capability, this approach is unlikely to be productive for programs of this complexity
- Ensure that the Services are responding to Department of Defense (DoD) priority decisions rather than inconsistent Service-assigned "urgency"

As noted in the Key Judgments, the flight test risk should be reduced to only those uncertainties that must be resolved in flight. Other issues should be resolved in ground testing. Flight testing should then be used for verification.

The attempt to achieve an early operational capability before EMD is workable for systems and capabilities that are reasonably well in hand. For complex, demanding tasks (i.e., HTK) that have yet to be demonstrated adequately, the drive for early capability is proving to be counterproductive.

The NTW program seems to have modified significantly the demand for early capability; however, the THAAD program continues to pursue this capability with undiminished zeal. The THAAD program should be relieved of this requirement, and the energy and resources should be channeled to the EMD program.

Program office briefings for all the HTK EMD programs stressed operational "urgency" as justification for accelerated, high-risk approaches. For some of these programs, the operational "urgency" generated by the Service seems out of proportion with the joint priorities and the program resources.

Recommendations for Reducing Flight Test Risk All BMD Programs (3 of 4)

- Need more rigorous ground testing that uses the best available simulations and test facilities
  - BMDO should conduct a comprehensive review of current and planned capabilities to ensure that facilities are adequate for testing and that funding will be available to support any necessary upgrades
  - BMDO should insist upon more—and more rigorous—HWIL testing of IR HTK systems
  - Need an approach similar to captive-carry, which permits sequential, repetitive, non-destructive test (NDT) and find and fix testing of critical flight software and hardware, such as that in the HTK vehicle

To ensure adequate HWIL test facilities and the best use of available facilities, BMDO should conduct a comprehensive review of current ground test capabilities, including capabilities that complement HWIL (e.g., tethered systems and hover test facilities).

Programs should embrace a testing approach that provides for sequential, replicable, non-destructive ground tests, with simulations and ground test facilities providing the supporting capabilities. End-to-end system simulation is vital to reduce flight test risk, and it should include more use of HWIL testing for critical flight hardware.

KV ground testing should include realistic scene generation as part of a HWIL capability for testing end-to-end KV performance.

If BMDO finds that facilities are not adequate for providing such capabilities to the extent needed for supporting the BMD programs, BMDO should place a high priority on a coherent, near-term investment program to fill the gaps.

A continuing program should also be in place to upgrade capabilities as needed.

Recommendations for Reducing Flight Test Risk All BMD Programs (4 of 4)

- BMDO, strongly supported by Under Secretary of Defense for Acquisition and Technology (USD(A&T)), needs to play a more compelling role in BMD programs execution
- BMDO should establish the following driving philosophy for flight testing for all HTK programs:
  - A complete environmental specification must be prepared so that all critical components are fully qualified for expected flight conditions, with adequate margins to handle the unexpected
  - Program office certification, prior to Flight Readiness Review (FRR), that:
    - All items have been qualified to at least 3 dB above predicted environments
    - All items have undergone rigorous ground testing
    - IR HTK seekers have been tested in rigorous high-fidelity HWIL simulations

BMDO must take a more active role in ensuring adequate preparation for flight testing. This will require aggressive BMDO initiatives and strong USD(A&T) support.

For example, BMDO should establish the driving philosophy indicated here. The environmental specification should ensure that critical components will have an adequate margin to deal with unexpected conditions.

A formal process is needed to ensure full certification of the system before each flight test. This process should include rigorous ground testing and software-in-the-loop (SWIL) and HWIL simulations.

Recommendations for Reducing Flight Test Risk NMD (1 of 2)

- Acknowledge that the 3 + 3 program schedule is very high risk
  - The start time for 3 + 3 was October 1996; however, the integrating contractor responsible for detailed program planning is not being selected until spring 1998
  - The program should be restructured now to eliminate unrealistic expectations
- Whether or not BMDO continues to pursue 3 + 3:
  - Restructure test flight programs to allow time between tests to ensure that testing is completely sequential—that is, allow adequate time between test flights to correct deficiencies and ensure that adequate assets are available for repeat tests
  - Increase funding for test assets and increase the planned testing to include a planned back-up test for the sensor fly-by (1a/2) and the intercept attempts (3/4)
  - Increase funding support for ground tests to ensure capability for comprehensive subsystem and end-to-end system testing
  - Continue to fund key technology development for the earliest system and for follow-on system capability improvements moving from demonstrated operational utility to increasingly robust counter-countermeasures

Expecting the required development and testing for deployment readiness to be completed by the end of 2000 is unrealistic. The NMD program should be restructured now to provide for adequate, sequential development and testing.

While the 3 + 3 program is not a UOES program in the sense used in THAAD, it carries similar potential for interference with an orderly operational system program. In particular, the 3-year development program is driven by the need to be ready to deploy 3 years later. This has led to a highly compressed and less-than-minimum flight and ground test program.

In any case, these specific recommendations will reduce the NMD risk.

The philosophy of the 3 + 3 program calls for continued evolution of capabilities in the period between a successful readiness review and the actual decision to deploy a system. This approach requires a continuing and vigorous key technology development program to ensure that the program continues to evolve to meet the changing capability needs over time.

Recommendations for Reducing Flight Test Risk NMD (2 of 2)

- To reduce the risk associated with the challenging Kinetic Kill Vehicle (KKV) performance issues, BMDO should mandate that the NMD program—operating through the lead system integrator—have both of the candidate KKVs rigorously tested at the Kinetic Kill Vehicle Hardware-in-the-Loop Simulation (KHILS) facility to determine their suitability for NMD

In addition to the emphasis in earlier Key Judgments and recommendations, KKV performance warrants extraordinary attention. As a minimum, BMDO should demand extensive testing of candidate KKV systems in the most capable facility—the KHILS.

Findings:
Responses to Specific Questions
in the Tasking

This section responds directly to specific questions. Some findings are repetitive points that have already made in the Key Judgments and the recommendations; however, the repetitive points tend to be those most in need of further emphasis.

Findings (1 of 8)

Review of T&E Paradigms Used in Past Successful Programs

- Program experience verifies that success depends on following proven paradigms:
  - Realistic system requirements
  - Schedule plans based either on successful experience or supported by the use of newer processes with shorter time spans
  - Design and systems engineering discipline with adequate design margins
  - Full component qualification
  - Adequate simulation and other ground testing
  - Adequate numbers of flight tests and sequential testing
  - End-to-end flight readiness evaluations
  - Top-quality people in government program offices and on contractor teams
- In addition, the nature of BMD programs demands additional emphasis on:
  - High-fidelity simulations
  - HWIL testing: need new approaches that allow for repetitive and iterative find and fix testing of expendable flight hardware—the BMD equivalent of captive-carry for air-to-air missiles
  - Demonstrating and maturing HTK technologies

The collective experience of the study group members suggests that a successful flight test program starts with a realistic schedule. There must be the time and the commitment for a system to pass through a disciplined design process and the painstaking intervening steps that make the system ready for each sequential flight test. Our collective experience also suggests that test dates have to be driven more by successful completion of events than by the calendar.

End-to-end flight readiness evaluations are essential. For BMD programs, these evaluations have too often been most evident and most thorough *after* a failure instead of *before* the flight test. These reviews consistently verified the validity of the historic flight test paradigm.

In addition to these historic paradigms that produced successful flight tests of complex systems, the characteristics of HTK programs demand increased emphasis on certain aspects of the paradigm (e.g., design margins, full qualification of components, careful analysis of critical functions and components, thorough ground end-to-end tests, and so forth). The challenge of HTK also warrants additional emphasis on HWIL testing and high-fidelity simulations.

The historic T&E paradigm is still valid and is essential to successful flight test programs, but it is not being adequately followed in BMD programs. This paradigm is affordable for HTK systems and is far less costly than the current, riskier approaches that produce flight test failures, program delays, and possible program failure.

Findings (2 of 8)

Review of Peacekeeper Missile Program and Spacecraft Programs

- Followed the principles listed in the previous slide
- Some key Peacekeeper missile program characteristics
  - Constant, very high-priority national program
  - A new generation of ICBM that is building on a history of past successes
  - Rigorous performance criteria
  - 6 years planned from selection of contractor to first flight (actually took 6 1/2 years)
  - Despite time pressures, high priority on adequate quantity of tests and adequate time between tests. Planned 20 test flights in 4+ years
  - Completed on schedule and achieved performance. 18 test flights required
- Successful spacecraft programs include:
  - Redundancy and design margins for critical functions
  - Rigorous qualification of components and subcomponents
  - End-to-end preflight checkout capabilities

The Peacekeeper program provides a prototypical example of a successful, high-priority development program. It is particularly noteworthy that there were intense pressures for early initial operational capability (IOC) for Peacekeeper—from the user, from the DoD leadership, and from the National leadership.

Further, the Peacekeeper program was a new generation of a proven weapon (the ICBM), which, while pushing the state of the art, did not demand any fundamental technology not already demonstrated.

Even so, the program took 6 1/2 years from start to first flight and had a rigorous, disciplined, flight test program with adequate time between tests to analyze results before the next test—a thoroughly sequential approach. The program reached IOC on time and with less than the planned number of test flights.

Highly relevant lessons also apply to BMD programs from a myriad of spacecraft programs: the need for very high reliability in critical systems, rigorous component and system qualification, and end-to-end ground checkout before the system is launched.

Findings (3 of 8)
Sprint Missile (SAFEGUARD)

- High-priority program
- Intense time pressures
- Program manager reported directly to the Director of Defense Research and Engineering (DDR&E) (Dr. Foster)
- Test planning and record
  - 42 missile tests in 5 years
    - 23 successes (S)
    - 9 partial successes (PS)
    - 10 unsuccessful (U)
  - First 10 shots: S, PS, U, U, U, U, PS, PS, PS, S

The Sprint Missile program, as an element of the SAFEGUARD system, is another example of a high-priority program that was executed under intense schedule pressures.

With this highly compressed test schedule, the first 10 tests were characterized by a high failure rate. However, this failure rate was made tolerable by the extensive planned series of tests that followed.

Findings (4 of 8)

Some Characteristics of Present HTK BMD Programs

- Failures were often described to the study group as random or anomalous
- Failures are rarely random or anomalous
  - THAAD failures resulted from poor design, fabrication, management, and quality control
  - Navy CTV-1 failure resulted from poor design
- Root causes of the failures include:
  - Unrealistic schedules
  - Underestimation of the difficulty of achieving HTK
  - Inadequate component and system qualification and ground test

The study group heard repeated references to "random" failures. However, few, if any, of these failures were "random"—a statistical matter. They were caused by poor design, test planning, and preflight testing deficiencies; poor fabrication; poor management; and lack of rigorous government oversight.

The tendency of the government and program managers to trivialize the causes of these costly failures, combined with the aggressive schedule discussed on the previous slide, has led to a "rush to failure."

We felt that the program managers—both government and contractor—underestimated the degree of difficulty in achieving HTK. The fact that the contractor simulations often predicted HTK 100 percent of the time gave us the impression that the contractors routinely underestimate the many things that can go wrong. We felt that this lack of appreciation for the complexity of the task continued after experience should have provided compelling evidence to the contrary.

Findings (5 of 8)

Examine How Best To Identify Likely Failure Modes; Recommend Practices and Preflight Test Options

- Success depends on a detailed, well-documented, integrated test plan vs. a plan for a series of demonstrations
- HTK program planning has been characterized by inadequate and/or compressed flight and ground testing. Requires an up-front commitment to repeat tests when needed
- Need adequate investment in spare systems and targets to repeat tests as needed
  - Need to avoid the temptation to declare success and move on to the next test when key test objectives have not been achieved
- Compressed test schedules lead to parallel testing that assumes a high degree of success and does not accommodate the need to incrementally find, fix, and retest when problems occur
- An acceptable probability of success depends on a very rigorous and disciplined subsystem and system development program with well-established and rigorous Program Design Reviews (PDRs), Critical Design Reviews (CDRs), qualification tests, and so forth. The importance of this approach grows exponentially with reduced numbers of flight tests

Success in flight testing has depended on detailed, well-documented, integrated test planning vs. depending on a series of leap-ahead demonstrations.

In contrast to this need, BMD HTK program planning has been—and much of it still is—characterized by inadequate and compressed flight and ground testing. Much of the testing is in parallel, with inadequate time between tests to correct problems before the next test. This situation is exacerbated by inadequate provisions to repeat tests that fail.

To the extent that cost or other factors demand minimum test flights, the importance of the other aspects (design margins, component qualification, ground tests, preflight review, and so forth) becomes even more critical.

Regardless of the approach, when developing new and unprecedented capabilities, flight test failures will occur. A prudent program will anticipate and account for this reality. Failures can be minimized with incremental, sequential testing; however, they cannot be eliminated.

Findings (6 of 8)

Examine How Best to Identify Likely Failure Modes; Recommend Practices and Preflight Test Options

- Need more rigorous ground testing that uses the best available simulations and test facilities
  - HWIL for critical functions
  - Need an approach similar to captive-carry, which permits sequential, repetitive, NDT and find and fix testing of critical flight software and hardware, such as that in the HTK vehicle
  - Realistic scene generation
  - Need end-to-end system simulation to include maximum critical HWIL
- Ground testing emphasis expanded greatly following failures. Needs to be an up-front requirement, not a response to failure

The study group found significantly increased emphasis on ground testing following test failures. We also found an array of existing capabilities for simulation and ground testing, including concepts that approach end-to-end preflight testing. We did not find consistently coherent plans to make the best use of this array of capabilities nor a rigorous analysis of remaining deficiencies and programs to fill those gaps.

We found approaches that might fill the function that captive-carry fills for air-to-air and air-to-surface missiles: providing find-and-fix opportunities for system interfaces and critical functions. These approaches included tethered systems with dynamic scene generation and expanded hover testing. This capability is critical for reversing the record of failures in HTK BMD programs. Again, we did not find the use or planned use of these approaches in BMD programs.

Findings (7 of 8)

Examine How Best to Identify Likely Failure Modes ; Recommend Practices and Preflight Test Options

- THAAD flight test experience indicates that the initial design and fabrication were not subjected to adequately disciplined engineering practices and rigorous quality control
- The NMD program, which will depend on an integration contractor for these functions, needs to pay intense attention to these lessons from the THAAD program
- Time pressures continue to inhibit the right level of discipline in the THAAD program
- The NMD program planning creates a high risk that these same pressures can drive NMD design and test philosophy

Since the THAAD program has produced the most flight test experience to date, it also provides the richest source of lessons learned for the NMD program.

Numerous reviews and the Integrated Product Team (IPT) process have reported that initial design and fabrication were not subjected to adequate discipline and quality control. Further, the THAAD program office has also expressed these concerns at various times.

To a large extent, the NMD program will depend on an integration contractor for these functions. The NMD program will need a rigorous approach for ensuring that the early THAAD experience is not repeated in NMD. The 3 + 3 approach leaves no room for the failures of proven technology that can be very nearly eliminated with discipline and quality control.

As already suggested several times, schedule pressure can be a powerful opponent of rigorous design, fabrication, and test discipline. The 3 + 3 approach is likely to produce intense schedule pressures.

Findings (8 of 8)
HWIL Test Facilities

- The BMDO-developed HWIL facility (KHILS) is underused
- Each Service is also investing in its own HWIL test facility, with little regard for available capabilities in other Services or agencies
- The technology needed to develop such facilities (e.g., scene generation and projection) is becoming less costly and more capable every year
- THAAD and NMD do not appear to be leveraging the capabilities in these facilities
  - THAAD has not subjected the seeker for FT-8 to the most rigorous testing
  - NMD does not appear to be planning such HWIL testing before the interceptor down-select

Even though an extensive array of simulation and test facilities are available, the study group was unable to find a comprehensive, coherent plan for their use and further development—particularly for HWIL testing of critical components.

A comprehensive review of the largely Service-and contractor-developed capabilities is urgently needed to provide a coherent plan for current use and for a DoD investment plan to fill future needs.

We found that the THAAD and NMD programs were not making maximum use of existing facilities. The THAAD contractor felt that the seeker for FT-8 did not need to be subjected to the most rigorous level of testing, because of the large target size in FT-8. The NMD program was also not planning use of the KHILS Facility to learn more about the two candidate seekers in its program.

Specific Program Reviews

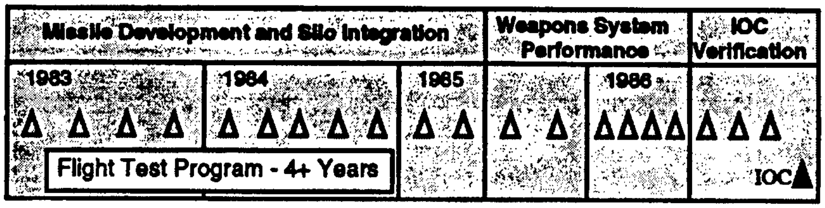
This section contains selected information from specific program reviews.

The study group received extensive reports on these programs from government and contractor program managers. This section focuses on the experience and lessons learned that are the basis for the key judgments and findings in the previous sections.

Peacekeeper ICBM Program

High Pressure, Careful Planning, Deliberate Execution

- National program, national priority
- Strong user demand for an early IOC. Still 6 years from start to first flight
- Strong requirements focus—both operational and test requirements



- Phased approach to reduce flight test risk
- Full qualification of individual components
- Ground tests to demonstrate subsystem performance
- Three phases
  - Phase 1: Does Peacekeeper work? Address technical risk areas early
  - Phase 2: How well does Peacekeeper work as a weapon system? Define final configuration and operational procedures
  - Phase 3: Is Peacekeeper ready for IOC?

The Peacekeeper ICBM program exemplifies a complex, high- priority program in which a highly successful flight test program was planned and executed in an environment of intense pressures for an early IOC.

The starting point was a strong and uncompromising requirements focus both for operational capabilities and test planning.

The test program was comprehensive, incremental, and sequential and provided time between tests to analyze, fix, and prepare for the next test. Partial failures did occur; however, in each case, the cause was confidently determined to have been aided by uncompromised instrumentation.

The program to control flight test risk followed the successful historic test paradigm: full qualification of components and subsystems, comprehensive ground tests, and disciplined sequential testing with time to fix deficiencies before the next test.

Peacekeeper ICBM Program
System Test Program

- Based on a full Test and Evaluation Master Plan (TEMP) and an Integrated Test Plan (ITP)
- The Peacekeeper ITP was the basis for all test planning analysis (TPA)
  - Defined 319 major ground tests and 20 flight tests for the development, test, and evaluation (DT&E) and the initial operational test and evaluation (IOT&E) phase
  - All test facilities, instrumentation, and test-unique accommodations on the operational system were based on the ITP and the detailed TPA
  - Instrumentation and test-unique accommodations were among the most challenging needs
- The TEMP also required the program office to establish and chair test planning working groups in which project officers, project engineers, contractors, the customer, and the independent test organization participated fully—including the resolution of anomalies

The system test program received intense attention, starting with a detailed TEMP and ITP that included detailed ground and flight test requirements.

All test activities, planning, execution, and review emanated from the TEMP and the ITP.

Test planning working groups were key players in flight test decisions.

THAAD

- Purpose: defend against medium- to long-range TBMs intercepting low-endo through exo-atmospheric targets with an HTK warhead
- Systems
  - New ground-based radar (GBR)
  - Launchers on a Palletized Load System (PLS) truck
  - Command and control (C2) system
    - Tactical operations station
    - Launch control station
  - New missile with an HTK KKV

The THAAD system consists of a new radar, launcher system, a complex C2 system, and a new missile that incorporates complex, unproven technology. This missile is planned to operate in altitude regimes from the low endo-atmospheric to the exo-atmospheric.

THAAD Flight Test Objectives and Results

FT	Objective	Result	Cause of Failure
1	Missile functions, propulsion	Success	
2	Midcourse functions, controllability	Range initiated destruct	No flare deployment, short in flare ordinance cable
3	Acquisition functions, target flyby	Target not designated	IAP overloaded with false alarms, FPA edge effects
4	Exo intercept	Missed target	Faulty GN&C logic
5	High endo intercept	Missed target	Lanyard connection failure
6	High endo intercept	Missed target	Seeker contamination most likely cause
7	High endo intercept	Missed target	DACS failed to operate because of a contaminated battery connector

The THAAD flight test program encountered difficulties beginning with the second test.

The causes of failure in these flight tests were found to be in subsystems usually considered to be low risk. The failures typically were caused by poor design and fabrication, inadequate ground checkout discipline, and pressures to move on to the next step. For FT-4, the cause of the failure could have been discovered with checkout processes that are fairly standard for systems of this type.

The failures led to extensive reviews. These reviews identified important shortcomings in design and fabrication discipline, test planning, ground testing, and preflight review.

THAAD: The Program Environment

Intense Time Pressure—Rush to Failure

- Intense time pressure on a UOES capability. Mismatch between department's priorities and reality of the program challenge
- Higher risk has been justified by urgent fielding requirement. Test preparation and instrumentation decisions influenced by desire for early decision on the 40 UOES missiles
- Myriad leadership and management concerns identified by the program office and independent reviews indicated that the time pressures had become counterproductive. The program needed fundamental reprioritizing
- Multiple additional external factors contributing to risk
  - Funding
  - Political pressures
  - Test range adequacy and availability
  - Targets

While the justification for the time pressure was the users' need for capability, the UOES approach to satisfying that need seems to have stemmed from seriously underestimating the difficulty of the task.

A conscious decision was made to trade off technical risk against the urgent need. This decision resulted in a program plan that would buy operational missiles and field an operational system of a type that had never been fielded before accomplishing EMD. This decision also led to serious compromise of the test missiles, requiring that the test missiles be essentially operational rounds with whatever instrumentation could be accommodated.

Following the early failures and continuing through the latest failure, numerous in-depth reviews (both internal and external) have identified the causes of the individual failures and the deeper underlying causes. However, there was little or no relief from the time pressure. The early program presentations to the study group—even after the failure of FT-7—emphasized the urgency of conducting FT-8, with minimum delay and virtually no increased ground tests. Subsequent decisions show some change to a more deliberate approach but with a continuing commitment to the UOES approach.

THAAD UOES System

A Symptom of Heavy Schedule Optimism

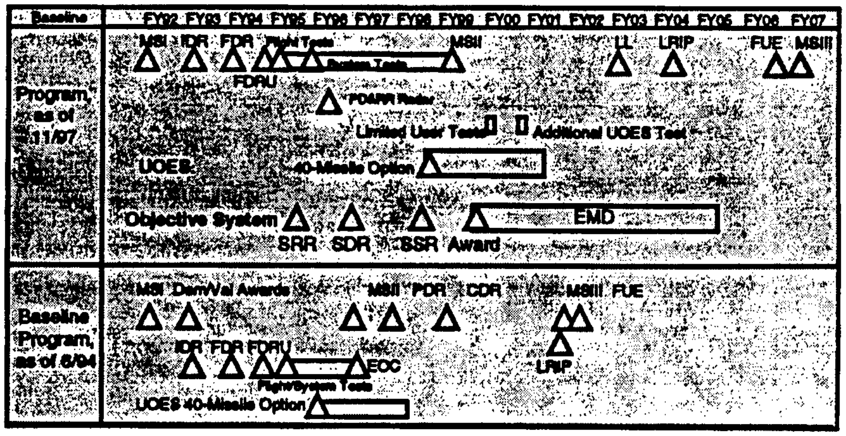
- Strategic Defense Initiative Organization (SDIO)-proposed and Congressionally mandated 1996 capability date
- Essentially demanded an operational capability before the missile was designed
- THAAD battalion at Fort Bliss was stood up in June 1995
  - 2 radars and battle management/command, control, communications, computers, and intelligence (BM/C4I) suites
  - 4 launchers and 40 missiles to be purchased after first intercept
- THAAD demonstration/validation (Dem/Val) to provide UOES
  - 48-month contract
  - First flight in 24 months
  - 20 flights (~ 1/month)
- Required that test missiles be certified rounds rather than highly instrumented research and development (R&D) missiles
- Demanded highly parallel testing vs. a sequential find and fix approach

The UOES concept was originated within SDIO and was included as part of the THAAD program at its inception. It was later written into law by the Congress. It required that an early operational capability—to include a ready unit—be stood up in 48 months. This necessarily led to an emphasis on those issues that have to do with operational capabilities: operational rounds, an all-up C2 system, trained soldiers, and so forth. This compromised accommodating the best practices for test missiles and the test program.

The study group found that program managers, based upon their previous experiences, assumed that the long poles were the radar, C2 system, and trained soldiers. They did not anticipate that guiding the missile to hit a target would prove to be the most daunting task. Again, this is evidence of underestimating the difficulty of performing HTK intercepts.

THAAD Program Schedules

Facing Reality but With Continuing Optimism



Mid-FY 96 Change (after the 4th consecutive failure to intercept)

- From: high-risk, accelerated hardware delivery with aggressive Dem/Val flight test schedule with Low-Rate Initial Production (LRIP) 21 months after EMD Authority to Proceed (ATP)
- To: risk averse event-driven flight test after EMD ATP schedule with LRIP 60 months after EMD ATP

This slide shows how the THAAD program schedule has slipped because of the failed flight tests and subsequent budget cuts. The schedule, as outlined in June 1994, called for FUE in 2002. The new schedule, shown in the top of the figure, adjusts to the failed flight tests and concurrent budget cuts. The completion of the test program has slipped 2 years, and FUE has slipped from 2002 to 2006.

Even now, the remaining test program is compressed, and the criteria for buying the 40 UOES missiles remains a single successful test. Consequently, the early capability pressure continues to compromise the test missile instrumentation.

THAAD
Aggressive Test Program
Changing Configurations and Goals

- The test conditions changed from flight to flight
  - Missile configuration
  - Guidance software
  - Intercept conditions (e.g., exo vs. high endo)
- FT-8 will fly a new seeker (InSb)
- Even after review groups recommended not changing configurations, THAAD will fly one interceptor on the upcoming FT-8 and FT-9 flights and a different interceptor on the FT-10 through FT-13 flights

The test missiles in the THAAD flight test program have undergone numerous changes between between FT-1 and FT-7. The study group found that the guidance software was written only to work on that particular test and under the expected conditions. Likewise, hardware changes were also occurring.

The new InSb seeker will fly on the upcoming FT-8. This will be the first test flight for this seeker.

Some THAAD Project Office Concerns Regarding the THAAD Contractor, August 1996

- Fundamental concerns regarded leadership and management
- Basic philosophy change was needed. Must adopt a system perspective
- Lack of high-quality personnel/functional experts
- No defined system engineering process
- Little evidence of system engineering talent infusion
- Software management and development process
  - Inadequate system level management
  - Disciplined process was not in place
  - Inadequate requirements documentation and stability
- Product assurance program was inadequate

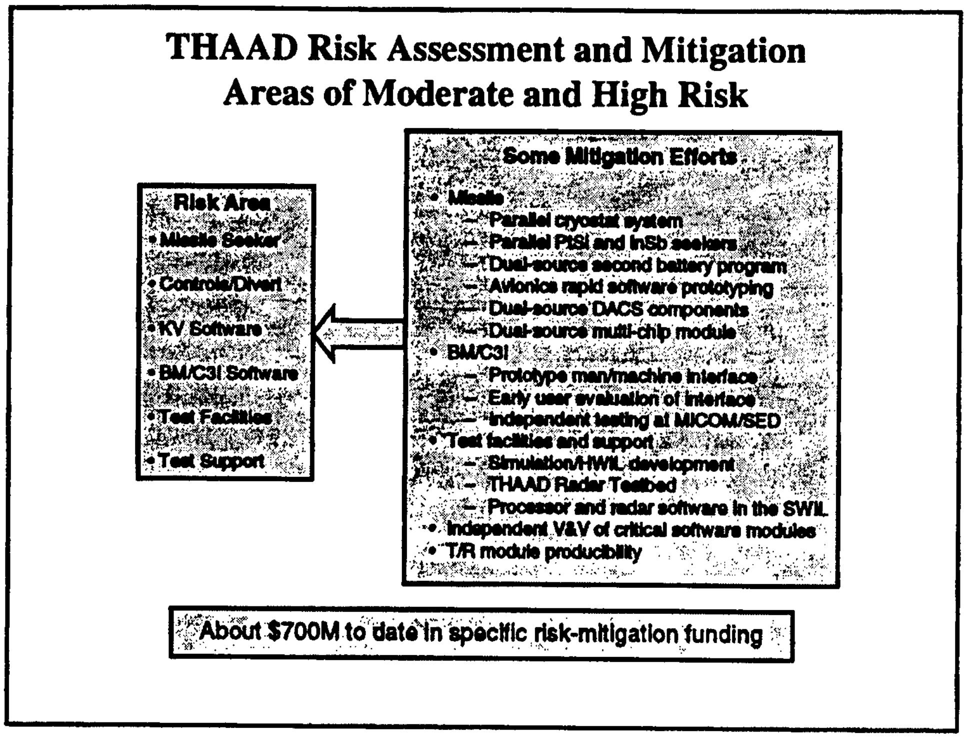
The THAAD program office also expressed concerns with the contractor program management. Again, the root causes were associated not only with the technological challenge but also with the basic set of disciplines essential to success in developing and testing complex systems.

It is not clear what actions were taken as a result of these concerns.

BMDO's Missile Assessment Team
THAAD Risk Areas—April 1997

- Missile design moderate risk areas: exo and high endo
  - Mission-critical functions
  - Processor usage
  - Autopilot boost/TVC
  - Booster separation ESD
  - Instrumentation design
  - System margins
  - Seeker design
  - Hit point performance
  - Wiring and grounding design
- Design evaluation/execution: moderate risk
  - Missile design evaluation
  - IAP FCT
  - One shot devices
  - KV-level ESS
  - DACS FCT and ESS
  - IMU FCT
  - Seeker
  - Flight simulation
  - KV wiring
- Design evaluation/execution: high risk
  - DACS built-in test and assembly test
  - Quality assurance program

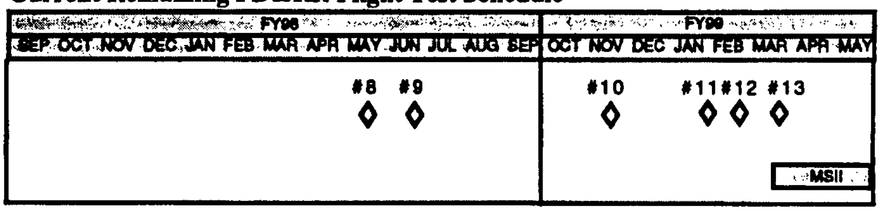
In April 1997, the Missile Assessment Team identified specific areas of moderate-to-high risk. This report was produced after the failure of FT-7. This list of significant risk areas, provided halfway through the planned test program, should have been compelling evidence of the compromising pressures on this program. Nonetheless, in late 1997, the program direction was still driving to maintain the flight test schedule to meet the users' "urgent" need.



The evidence is that the continuing incidence of moderate- and high-risk areas this late in the test program is not caused by a lack of understanding of risk areas. The THAAD Program has spent $700M toward risk mitigation. It is more likely that the difficulty lies in the initial unrealistic schedule and the continued attempts to keep a compressed flight test schedule moving forward.

Remaining Dem/Val Flight Test Program
13 Flight Program for THAAD

Current Remaining PD&RR Flight Test Schedule



This slide shows the flight test schedule as of early February 1998. FT-8 has now been delayed because of difficulties discovered during ground testing. Even so, given the history to this point, the remaining schedule still appears to be compressed and optimistic, particularly since the end of the test period remains unchanged with FT-11, -12 and -13 being compressed to make up for the slip in FT-8, -9 and -10.

THAAD Analysis Simulations

The Capabilities Vs The Practice

- THAADSIM-HWIL
  - Simlab real-time HWIL simulation (6 DOF). High-fidelity simulation for software testing, analysis, and qualification. Also hardware integration and interface testing
  - THAADSIM-D
  - Simlab non-real-time, all-digital simulation (6-DOF)
- THAADSIM-A
  - Non-real-time, all-digital simulation (6-DOF). Reduced fidelity flight software modules to allow UOES, EMD analysis
- End-to-end
  - THAAD non-real-time, all-digital simulation (5/6-DOF). Analysis of systems level sensitivities to target uncertainties, radar errors, in-flight updates, and so forth
  - Scientific, engineering, and technical assistance (SETA) sims
  - SETA contractor simulations (3 and 6 DOF). Used for baseline comparisons to help verify models, algorithms, and missile/weapons system performance

The inadequate simulation and ground testing is probably not caused by the lack of facilities or capability. The study group found the combinations of computer simulation and HWIL capabilities to be impressive, though not complete.

The difficulty, again, seems to stem more from a mindset that limits ground testing to the minimum essential to proceed with the flight test schedule.

THAAD
Observations

- HTK is a very difficult task. Attempting an operational capability before EMD is high risk and beyond our experience
- The THAAD program places a high priority on achieving a high-risk UOES capability. In execution, the UOES program is a diversion from the objective system
- The UOES requirement was designed to help meet an urgent need but:
  - Led to a highly concurrent program
  - Demanded parallel testing
  - Compromised the missile test program
  - Has not produced early capability
  - Continues to impact program management in spite of rebaselining and reevaluation

The study group's purpose was not to evaluate the THAAD program but to extract lessons that would be useful to the NMD program. Still, immersion in the THAAD program led to the obvious observations on this slide and the following slide—observations that are relevant to the THAAD program and to NMD planning.

THAAD
Observations (Continued)

- Because of the test failures, program management recognizes the need for a more conservative approach with performance vs. calendar milestones. However, schedule pressures persist
- Decision to exercise 40-missile buy is still based on a single successful intercept vs. the more conservative LRIP criteria (3 intercepts)
- Need clear recognition that success in meeting the need—no matter how urgent—will depend on a design with adequate margins and on engineering and fabrication discipline
- The program has been examined through a myriad of independent reviews that reported these problems
  - Program management will have difficulty adjusting to the realities of schedule and technical challenge as long as the intense schedule pressure persists

NTW Theater Ballistic Missile Defense (TBMD)

- Purpose: defend against medium- to long-range TBMs with exo-atmospheric intercepts with a HTK warhead
- Systems
  - TBM detection and tracking: Defense Support Program (DSP) and AEGIS system
  - Missile: Standard Missile-3 (SM-3)
    - HTK with LEAP
  - C2: AEGIS Combat System

NTW is an evolutionary development based on the proven AEGIS and Standard Missile programs. However, it adds important new challenges: SM-3 flight outside the atmosphere, sensor upgrades to meet new discrimination requirements, and a variety of KV challenges with the LEAP KV. In addition, it includes a dual-burn solid rocket third stage and an IR thermal guidance system.

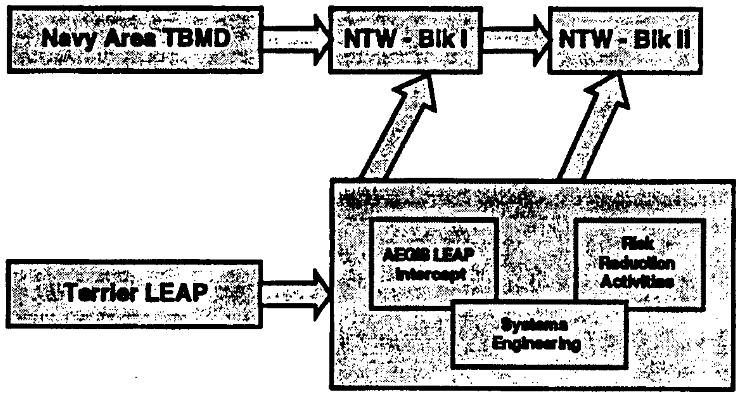
SM-3 Programmatic Background

- Four LEAP intercept attempts (Army LEAP 2 and 3 and Navy Terrier LEAP 3 and 4)
  - Four different configurations
  - All compressed schedules
  - All failed
- Numerous review panels and "lessons learned" studies. Common threads:
  - Successful intercept demonstration essential to continuation of the program
  - Measured, incremental test program essential
  - Configuration variations and changes must be minimized
  - Comprehensive end-to-end system testing of flight configuration essential to risk reduction
  - Need spare missile flight assets
  - Avoid rush to failure

As is the case with THAAD, operationally useful HTK is yet to be demonstrated in this program employing different HTK technologies. The four attempts in the precursor Army LEAP and Navy Terrier LEAP program were all failures. An extensive outside review by an independent Blue Ribbon Panel led to the decision not to continue the Terrier LEAP program but, instead, to move to the AEGIS Leap Intercept (ALI) program while retaining the emphasis and the mandatory milestone of demonstrating HTK capability.

The ALI program should benefit from numerous previous reviews that stressed the need to temper the drive to meet the "urgent" need with the reality of the difficulty of the task.

NTW Program Evolution



This slide illustrates the legacy and the evolution of the NTW program. As discussed, the ALI program follows the Navy's Terrier LEAP program in a continued effort to prove the HTK capability of the LEAP vehicle.

The NTW program has been significantly modified since the study group began its work, with an earlier UOES concept giving way (at least on briefing charts) to a block concept.

Block I capability is seen as a legacy of the Navy Area Defense Program. The Area Defense program uses a different missile (the SM-2 Blk IVA missile with an explosive warhead) and the AEGIS Combat System.

The ALI program is a risk-reduction activity within the NTW Defense program. It is designed to prove the exo-atmospheric operation of SM-3 and the LEAP vehicle.

NTW
The Program Environment

- Initially, intense time pressure for an early capability. Mismatch with department's funding priorities
- Higher risk considered justified by "urgent" fielding requirement
- Multiple additional external factors contributing to risk:
  - Funding
  - Defense industrial base
  - Political pressures
  - Test range adequacy and availability
  - Targets
- Initial phase focused to demonstrate that LEAP can hit a target in space

Intense time pressure is also a legacy for the NTW. Earlier direction from the Secretary of the Navy and the Chief of Naval Operations (CNO) emphasized the urgency for NTW and, therefore, the willingness to accept risk. There may also be some sense of competition with THAAD.

This time pressure and a number of other factors—including significant resource instability and an incomplete set of requirements—continue to contribute to risk.

ALI Program Scope

An Essential but Limited Step

- AEGIS weapons system
  - AN/SPY-1B/D radar
  - Command and decision
  - Weapons control system
  - Vertical launch system
- SM-3 LEAP interceptor
  - SM-2 Blk IV propulsion chain
  - Third-Stage Rocket Motor (TSRM)
  - KV fourth stage
- Aires target

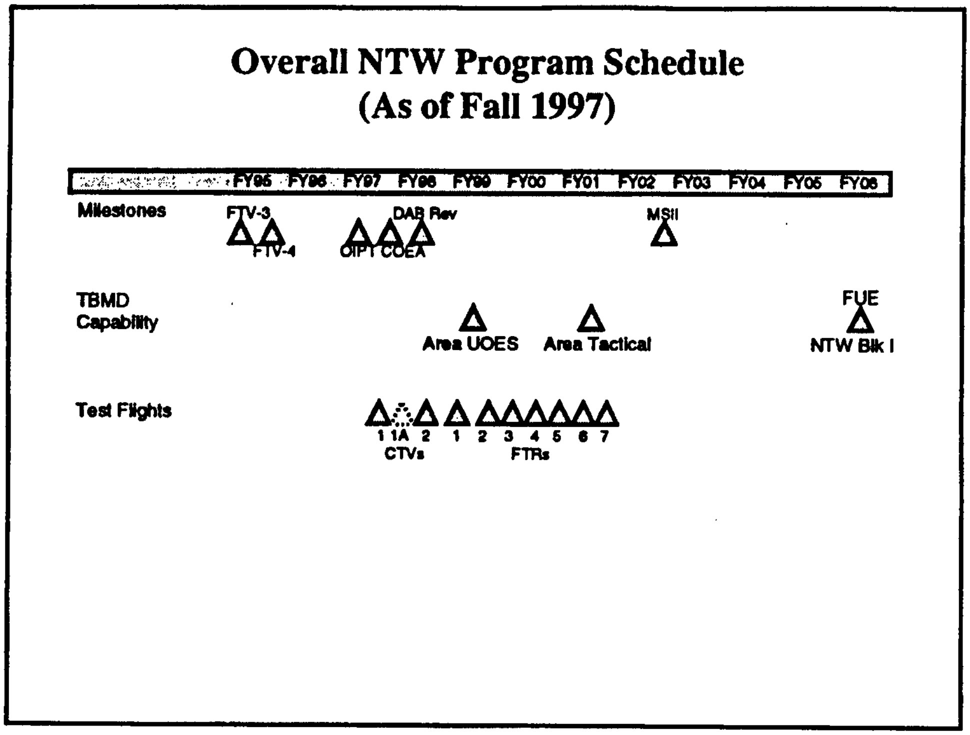
The ALI program is the currently defined phase of NTW. Its goal is to reduce the risk of exo-atmospheric intercepts by performing early testing. It is a tightly focused project to demonstrate that the SM-3 can deliver the LEAP vehicle into the needed basket and that the LEAP vehicle can hit a target in space. It does not include the kind of performance specifications that will define the follow-on operational system or will serve as the basis for the flight test program. That work is yet to come.

Top-Level ALI Missile Requirements

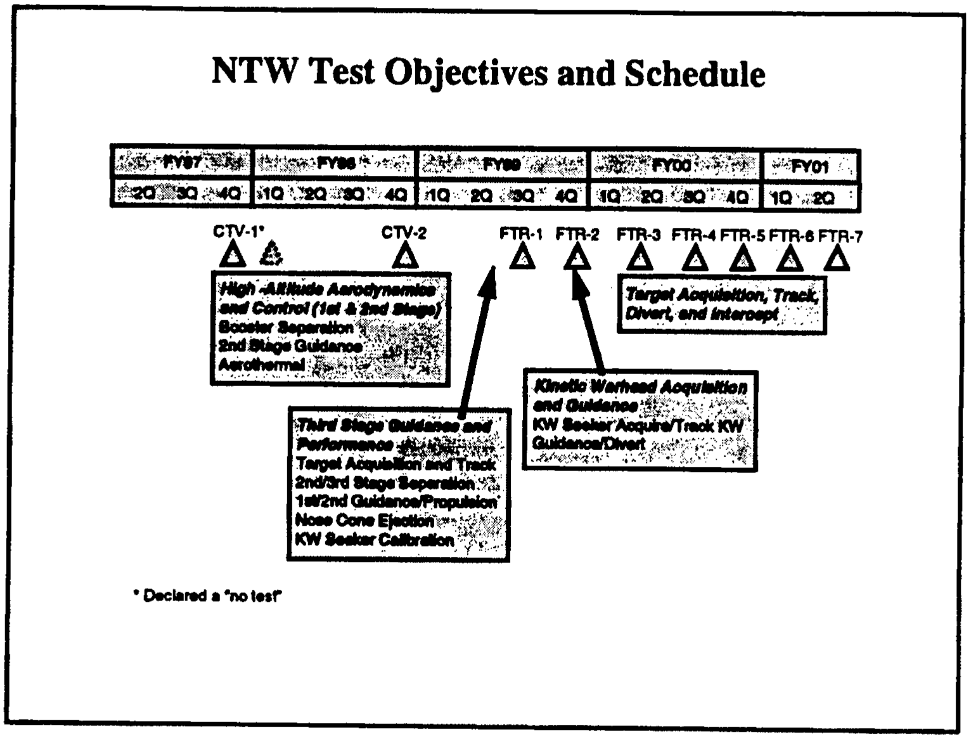
- Threat range: 500–1,000 km
- Missile architecture derived from SM-2 Blk IV and Terrier LEAP hardware and software
- V_{bo} ~3.4 km/sec
- Nuclear environment not imposed
- Lethality and discrimination not specified

As discussed, many of the essential operational characteristics for the NTW are not yet defined. Hence, while success in the ALI program is an essential precursor to NTW development, it is only a precursor and should not lead to schedule optimism in developing and testing an operational system. For example, defining and meeting discrimination requirements are essential for an effective operational system. This could be at least as daunting as demonstrating HTK capability.

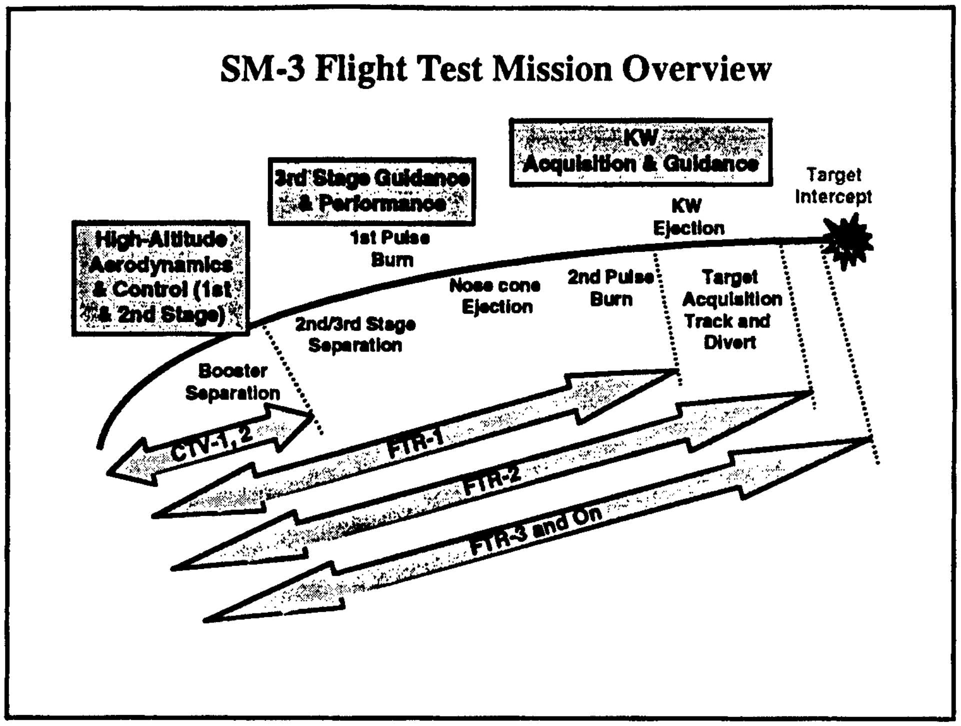
The NTW program has realized the difficulty of solving the discrimination problem. In a set of risk-reduction activities in parallel with ALI execution, it has funded a joint system level [radio frequency (RF)/IR)] discrimination effort with technical support from the Johns Hopkins University/Applied Physics Laboratory (JHU/APL); the Massachusetts Institute of Technology/ Lawrence Livermore (MIT/LL); the Lockheed Martin/Government Electronic Systems (LM/GES) (AEGIS Weapon System); and the Standard Missile Company (SMCo) (SM-3 missile). This effort is to determine and develop the required discrimination algorithms and accompanying equipment.



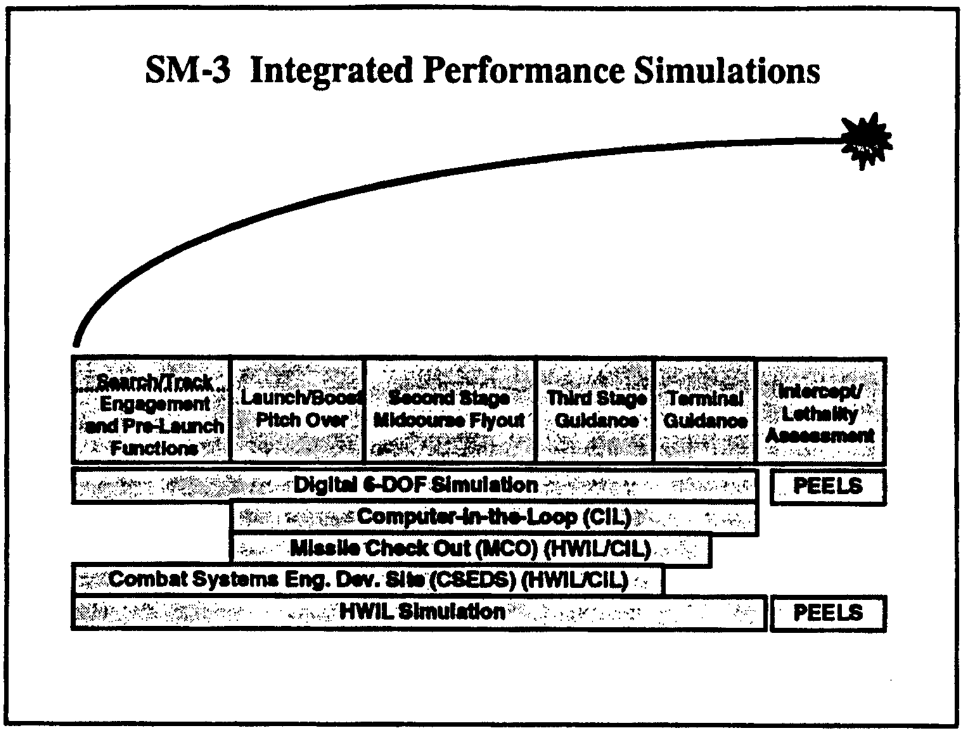
The flight test schedule calls for seven test flights over a period of 4+ years. This schedule is well within the realm of reason; however, given the failure of CTV-1, the start date may be optimistic.



At the moment, it appears that given the right focus on qualifying components, ground tests, and preflight review, the flight test schedule and objective now appear to be incremental and sequential.



This slide further illustrates the incremental and sequential nature of the currently planned flight test program. The study group was unable to discover an equally well-defined program of ground testing.



There does appear to be a reasonably comprehensive set of planned simulation and HWIL test capabilities that could accommodate a comprehensive ground test program. Some combination of computer and HWIL is available to evaluate capability from launch to kill. However, it is not clear that these simulations are connected as needed to provide an end-to-end preflight evaluation.

ALI Program's Risk Items for SM-3
December 1997

- High
  - TSRM forward closure
  - KW envelope
  - KW weight
  - KW seeker contamination
- Moderate
  - Nose cone - thermal adequacy
  - KW TE console
  - Nose cone structural adequacy
  - Nose cone separation adequacy
  - XSMDC performance
  - Concurrent development testing
  - TSRM case: aero heating
  - Solid Divert and Attitude Control System (SDACS): schedule
  - TSRM weight
  - CTV-2 LRIP hardware availability

The ALI program continued to carry a significant list of high- and moderate-risk items in December 1997. At the minimum, this suggests that much work needs be done to conduct a flight test program with acceptable risk.

Study Group's Observations on NTW

- The program was initially under intense time pressure. It is not clear how that has been adjusted even though the schedule has been substantially extended
- The NTW early capability goal seems on the path to the objective system, but the objective system is only partially defined
- The ALI program is sharply focused on job #1: demonstrating that the LEAP can hit a target
- The overall ground test program to include facility use was not yet available. In particular, a plan has to be developed for the best available HWIL simulation of the KKV seeker
- The required discrimination capability—a key to a useful operational system—is not defined

This slide lists some of the more obvious observations about the NTW program. While there has been intense time pressure to field some early NTW capability, it is not clear whether this is a distraction on the path to the objective capability since that capability has not been defined. In any case, the program is firmly focused on the essential precursor of demonstrating the ability to hit an incoming target.

While there is a reasonably detailed flight test program for the ALI, the study group was unable to discover an adequately detailed ground test program.

Further, a key operational parameter for any exo-atmospheric system—the discrimination requirement—is yet to be defined.

Patriot Missile Program

- Purpose: point defense against TBMs using low-endo intercept with a HTK warhead and defense against cruise missiles and attack aircraft
- PAC-3 system evolved from PAC-2
  - ERINT HTK missile
  - PAC-2 Guidance Enhancement Missile (GEM) missile
  - Engagement control station

The Patriot PAC-3 program has several important characteristics that are significantly different from the other HTK TMD programs. It employs somewhat more mature technologies. More importantly, the Patriot program offices—government and contractor—are mature organizations with well-established processes and a proven history of program success. Further, the program has benefited from a consistent high priority. Hence, while HTK is still a difficult task for Patriot PAC-3, the program seems well organized to deal with the risks.

Patriot
The Program Environment

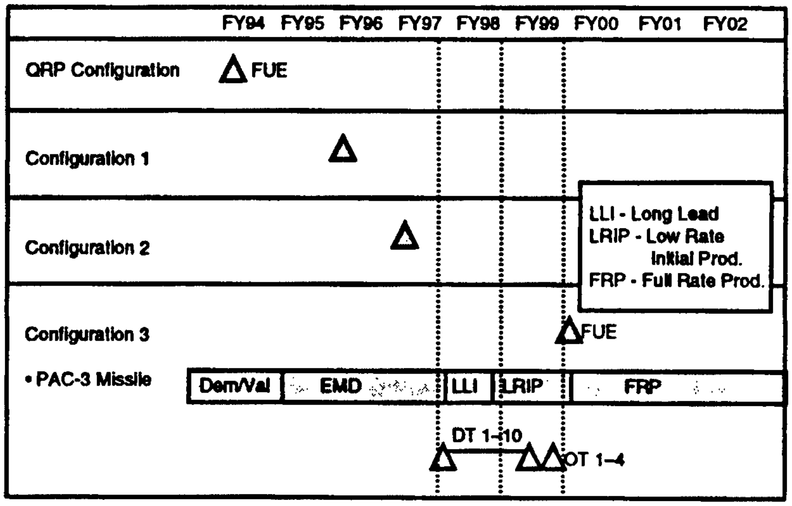
- Acquisition streamlining
- Budget and schedule pressures
- Minimal flight test and test resources
  - 2 Control Test Flight (CTF) missiles
  - 16 PAC-3 Guided Test Flight (GTF) missiles (10 fired at TBM targets)
  - 6 Patriot missiles (1 fired at a TBM target)
- Strong reliance on simulations
- Roughly 4 years from the start of contract to first test flight

The Patriot program has a full plate of challenges. Acquisition streamlining impacts the way the government and the contractor share responsibilities. While the impacts in the long term are likely to be positive, the short term may be turbulent.

Even though the program has been characterized by a constant high priority, budget and schedule pressures still abound. One consequence of these pressures is a minimal flight test program with strong reliance on simulations. The extensive use of simulations in preparation for flight test should be a substantial benefit. At the same time, the cost-effectiveness benefit of simulations in lieu of an adequate flight test program is far more problematical.

The study group notes that the PAC-3 missile program took roughly 4 years from the start of the contract until the first flight. This program built upon a base of contractor experience with the earlier ERINT system. This is in contrast to the THAAD effort, in which the goal was first flight within 2 years of the contract award.

Patriot PAC-3 Program Schedule
As of November, 1997



Since the Patriot system has a dual mission, much of the phased development program deals with radar and C2 requirements for the air breathing threat and for the TMD threat.

The Quick Response Program (QRP) configuration includes radar enhancements, remote launch capability to extend the missile coverage to the limits of the radar, and tactical command system upgrades.

Configuration 1 expands the C2 capabilities and introduces the PAC-2 GEM.

Configuration 2 includes additional enhancements to the radar and C2 system and some survivability enhancements.

Configuration 3 includes the HTK PAC-3 missile along with additional radar, remote launch, and C2 development.

PAC-3 Missile TBM Flight Test Matrix

Mission	Objective
DT1*	Initial flyout, aero data, airframe, uplink/downlink (UL/DL) operation
DT2*	Flyout to extended range, in-flight alignment, thermal effects
DT3	Missile-System Integration, low altitude
DT4	Missile-System Integration, high-altitude
DT5	Low magnitude helix maneuver, remote launch
DT6a	Accuracy maneuver, multiple objects in seeker field of view (FOV)
DT8a,b	High-magnitude helix maneuver, multiple TBM, turndown
DT9a	High-altitude intercept
OT1a	Multiple threat engagement
OT2a,b	Low radar cross-section (RCS)/high-velocity target, shoot-shoot firing
OT4a,b	Multiple TBM engagement, inner boundary engagement

* Flights DT1 and DT2 did not involve targets or intercept attempts

This slide shows that part of the flight test program was directed at the TBM mission. The sequential nature of objectives is noteworthy. However, it is also noteworthy that each flight breaks new ground with a significant advances in functionality.

PAC Models and Simulations

- PAC-3 SIM: digital end-to-end system simulation
  - High-fidelity radar, 6-DOF missile, missile lethality
- Flight mission simulator (FMS): exercises fully integrated ground system
  - HWIL tactical radar, simulated target RF, PAC-2 and PAC-3 environments
- Guidance Test and Simulation Facility (GTFS): design tool - support
  - HWIL ground and missile pre-launch, launch, and guidance functions
- Missile Command (MICOM) MSS-2: launch-to-intercept closed-loop simulation to measure overall system performance
  - HWIL: ground system models with tactical seeker, 3-axis motion table in an anechoic chamber, flight dynamics in the RF environment
  - Lockheed Martin Vought Systems (LMVS) HWIL Facility: PAC-3 missile flight hardware and software integration and checkout
- Multifunction simulation (MFSIM): high-fidelity modeling of Patriot system TBM, non-TBM, track, guidance, and search radar loading

As mentioned, there is an extensive set of simulations, including HWIL, available for the Patriot PAC-3 system.

DT-1 Flight Test Readiness Reviews CTF Missile

- PFTR 1.1: completed 3 June and 1 July 1997 in Dallas, Texas
  - Assess readiness to ship DT-1 missile forebody
- PFTR 1.2 - completed 18 September 1997 in Huntsville, Alabama
  - Assess integrated system readiness for final DT-1 processing
- PFTR 1.3 - completed 25 September 1997 in White Sands Missile Range, New Mexico
  - Assess Patriot PAC-3 system readiness to proceed to DT-1 launch

DT-1 Test Results: Missile System Performance Nominal

The Patriot program also makes use of an extensive flight test readiness review process. This slide shows the series of reviews conducted for the DT-1 flight of fall 1997.

PAC-3 - Observations

- While the program builds on a long development history, HTK is still a new and challenging task
  - The PAC-3 missile is a large step up from ERINT
- While the need for the TMD capability is urgent and PAC-3 is a high-priority solution to part of the need, the program urgency does not seem to be driving to high-risk approaches
- The Patriot PAC-3 program seems to be proceeding toward the objective system without pressures for an interim capability
- The long history of the Patriot program provides a legacy of disciplined design and engineering processes
- The program makes heavy use of high-fidelity simulations and HWIL simulations to reduce flight test risk
- The flight test program seems minimal, compressed, and concurrent. The flight test program and key program milestones are compressed

Some highly evident observations about the Patriot PAC-3 program are provided in this slide.

The NMD Program

In this section, the study group presents some relevant information about NMD and our reactions to it.

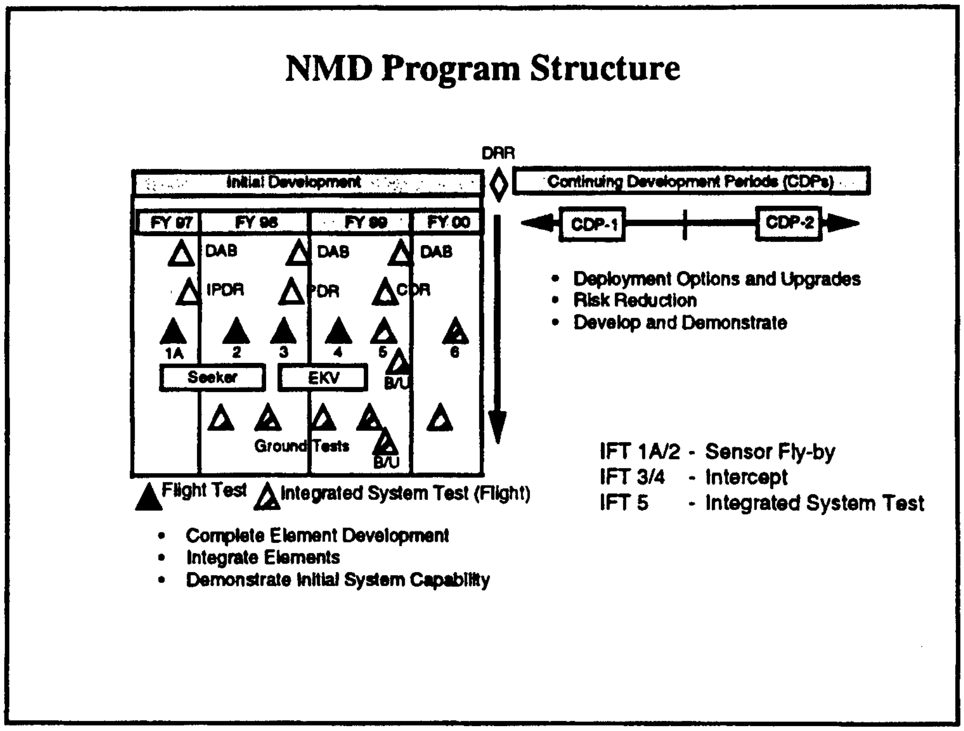
NMD Program

- Purpose: "to develop, demonstrate, and deploy an initial land-based national missile defense (NMD) system to defend against limited strategic missile attacks and be capable of evolving to counter future threats."
  - U.S. defense (all 50 states)
  - Assured human-in-control
- 3 + 3
  - 3 years (1999) to reach readiness to deploy in 3 years (2002). In the interim, continue to develop and improve the NMD system
  - Readiness to deploy review in 2000
- System architecture: "plug and defend"
  - Flexible systems engineering and integration
  - Respond to unknowns in threat and constraints

The current approach to preparing for NMD deployment introduces new and very demanding complexities. The current plan calls for bringing the system to a state of maturity by the end of 1999 such that the system is within 3 years of deployment. In the worst case, that would require deployment in 5 years.

While the readiness review in 2000 would theoretically modify the expectation, the very high visibility of this program is likely to produce intense pressures to maintain the schedule. Hence, the program begins with many of the problems that have beset other HTK programs: compressed schedule, minimal flight test, and poorly defined test objectives.

In addition, the funding for the program has been erratic at best and the program management approach depends to an unprecedented degree on an integrating contractor—again, an intriguing but unproven approach for a program that is to do something that has never been done before.



This rendition of the program structure calls for an integrated systems test in FY99 on the fifth test flight—about 1 year after the first intercept attempt, which occurs on the third test flight.

There is one backup integrated systems test flight available before the readiness review in 2000.

This schedule appears to be significantly more compressed and optimistic that the TMD programs schedules that have proven to be excessively challenging.

NMD System Risks

System Risk	Concern	Mitigation
T&E Program Scope	• Number of tests before deployment	• Increased funding / added more tests / added spares
System Discrimination	• Ability of elements to acquire data, fuse data, and discriminate reentry vehicle (RV) in a time-constrained environment	• Increased development, testing and validation of discrimination algorithms • Dual EKV sensor approach
System Siting	• Construction timelines • Easements • Environmental impact statements	• Incremental deployment • Congressional waivers • Selected sites/EIS process
External Integration	• Stressing timeline of required integration with external agencies	• Integration plans developed and being implemented

The program office recognizes the fact of high risk associated with the minimal flight test schedule and the very difficult discrimination challenge. Non-technical program challenges are also recognized. However, the program has not yet matured to the point of identifying the specific set of risks that need to be addressed. That activity will have to await the work of the integrating contractor.

NMD Test Risk
Test and Target Spares

- Spare booster available for all flights
- Front section spares formed from a combination of spare components and pulling subsystems from succeeding planned flights
- Target spares formed by pulling target object from succeeding planned flights

Spare test assets are a partial answer to the high-risk test program. However, it appears that the current plan for obtaining spares, shown on the slide, is minimal at best.

NMD Risks and Mitigation
System Discrimination (EKV)

- Risks
  - Battle Management/Command, Control, and Communications (BM/C3) fusing different types of sensor data
  - EKV combining IR sensor images with ground-based interceptor (GBI) IR discrimination algorithms
  - EKV target discrimination
- Mitigation
  - Parallel EKV contractor competition
  - Transition technology activities
    - Rad hardening/mercad telluride technology
    - Focal plane/silicon array technology

The discrimination problem for NMD is very challenging. The information on this slide was provided by the NMD JPO. The mitigation techniques proposed here are noteworthy but are not adequate to cover the range of risks already identified.

NMD T&E Risk Reduction

Risk Areas for T&E Resolution

- Limited system level testing
- Threat target realism
- Lack of spare test articles
- Multiple target tests
- NMD interoperability testing

BMDO-Proposed T&E Risk-Reduction Actions

- Additional integration facility for pre-IFT test
- Target object inventory: RVs, decoys, balloons, and so forth
- Spare test expendables
- Upgrade launch support at Meck Island
- Increased risk-reduction flight tests
- More simulation, test, and evaluation process

Specific T&E risks are currently being addressed by the NMD JPO with this set of risk-mitigation measures. While these measures seem necessary, they do not do much to relieve a very demanding development and test schedule.

Meetings and Site Visits

Meetings of the Study Group at the Institute for Defense Analyses (IDA)

- September 25–26, 1997
- November 5–6, 1997
- December 12, 1997
- January 15–16, 1998

Site visits occurring in December 1997 and January 1998

- Kinetic Kill Vehicle Hardware-in-the-Loop Simulation (KHILS) Facility, Eglin Air Force Base (AFB), Florida
- U.S. Army Aviation and Missile Command (AMCOM), Huntsville, Alabama
- Standard Missile Company (SMCo), Tucson, Arizona
- Lockheed Martin, Sunnyvale, California
- Lockheed Martin Vought Systems (LMVS), Arlington, Texas
- Pacific Missile Range Facility (PMRF), the island of Kauai in Hawaii
- Integrated System Test Capability Facility, Huntsville, Alabama
- Guidance System Evaluation Laboratory, Laurel, Maryland

GLOSSARY

AFB	Air Force Base
ALI	AEGIS LEAP Interceptor
ATP	Authority to Proceed
BM/C3	battle management/command, control, and communications
BM/C3I	battle management/command, control, communications, and intelligence
BM/C4I	battle management/command, control, communications, computers, and intelligence
BMD	ballistic missile defense
BMDO	Ballistic Missile Defense Organization
C2	command and control
CDP	Continuing Development Period
CDR	Critical Design Review
CIL	computer-in-the-loop
CNO	Chief of Naval Operations
COEA	Cost and Operational Effectiveness Analysis
CSEDS	Combat Systems Engineering Development Site
CTF	Control Test Flight
CTV	Control Test Vehicle
DAB	Defense Acquisition Board
DACS	Divert and Attitude Control System
dB	decibel
DDR&E	Director of Defense Research and Engineering
Dem/Val	demonstration/validation
DoD	Department of Defense
DOF	degrees of freedom

DOT&E	Director, Operational Test and Evaluation
DRR	Deployment Readiness Review
DSP	Defense Support Program
DT	development test
DT&E	development, test, and evaluation
DTSE&E	Director, Test, Systems Engineering and Evaluation
EIS	Environmental Impact Statement
EKV	Exo-atmospheric Kill Vehicle
EMD	Engineering Manufacturing Development
EOC	Early Operational Capability
ERINT	Extended Range Interceptor
ERIS	Exo-atmospheric Reentry Intercept System
ESS	environmental stress screening
FCT	flight confidence test
FDR	Final Design Review
FDRU	Final Design Review Update
FMS	flight mission simulator
FOV	field of view
FPA	focal plane array
FRP	full rate production
FRR	Flight Readiness Review
FTR	Flight Test Round
FTV	Flight Test Vehicle
FUE	first unit equipped
FY	fiscal year
GBI	ground-based interceptor
GBR	ground-based radar
GEM	Guidance Enhancement Missile
GN&C	guidance, navigation, and control
GTF	Guided Test Flight

GTFS	Guidance Test And Simulation Facility
HOE	Homing Overlay Experiment
HTK	hit-to-kill
HWIL	hardware-in-the-loop
IAP	Integrated Avionics Package
ICBM	Intercontinental Ballistic Missile
IDA	Institute for Defense Analyses
IDR	Initial Design Review
IFT	Integrated Flight Test
IMU	inertial measurement unit
InSb	Indium Antimonide
IOC	initial operational capability
IOT&E	initial operational test and evaluation
IPT	Integrated Product Team
IR	infrared
ITP	Integrated Test Plan
JHU/APL	Johns Hopkins University/Applied Physics Laboratory
JPO	Joint Project Office
KHILS	Kinetic Kill Vehicle Hardware-in-the-Loop Simulation
KKV	Kinetic Kill Vehicle
km	kilometer
KV	kill vehicle
KW	kinetic warhead
LEAP	Lightweight Exo-Atmospheric Projectile
LL	Long Lead
LLI	Long Lead Item
LM/GES	Lockheed Martin/Government Electronic Systems
LMVS	Lockheed Martin Vought Systems
LRIP	Low Rate Initial Production

MCO	missile checkout
MFSIM	multifunction simulation
MICOM	Missile Command
MICOM/SED	Missile Command/Software Engineering Directorate
MIT/LL	Massachusetts Institute of Technology/Lawrence Livermore
MSI	Milestone I
MSII	Milestone II
MSIII	Milestone III
NDT	non-destructive test
NMD	National Missile Defense
NTW	Navy Theater Wide
OIPT	Overarching Integrated Product Team
PAC	Patriot Advanced Capability
PD&RR	Program Definition and Risk Reduction
PDR	Program Design Review
PEELS	Patriot End-to-End Lethality Simulation
PFTR	Patriot Flight Test Review
PLS	Palletized Load System
PMRF	Pacific Missile Range Facility
PtSi	Platinum Silicide
QDR	Quadrennial Defense Review
QRP	Quick Response Program
R&D	research and development
RCS	radar cross-section
RF	radio frequency
SDACS	Solid Divert and Attitude Control System
SDIO	Strategic Defense Initiative Organization
SDR	Systems Design Review
SETA	scientific, engineering, and technical assistance
SM-2	Standard Missile-2

SM-3	Standard Missile-3
SMCo	Standard Missile Company
SRR	System Requirements Review
SWIL	software-in-the-loop
T&E	teat and evaluation
T/R	transmit/receive
TBMD	theater ballistic missile defense
TEMP	Test and Evaluation Master Plan
THAAD	Theater High Altitude Area Defense
TMD	theater missile defense
TPA	test planning analysis
TSRM	Third-Stage Rocket Motor
TVC	Thrust Vector Control
UL/DL	uplink/downlink
UOES	User Operational Evaluation System
USD(A&T)	Under Secretary of Defense for Acquisition and Technology
V&V	validation and verification
V_{bo}	velocity at burnout

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